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INFLATABLE BODY AND HEAD RESTRAINT

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This investigation established the feasibility of using an automatically inflatable restraint system as an alternative to the conventional restraint worn by helicopter crewmen. This type restraint provides increased crash protection because it provides automatic pretensioning which forces the occupant back in his seat, thereby reducing dynamic overshoot; reduces strap loading on the wearer when the inflated restraint is compressed during crash loading; reduces the concentration of strap loads on the body because of the

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increased bearing surface provided when the restraint is inflated; reduces head rotation and whiplash induced trauma.

SUMMARY

INTRODUCTION

The large number of helicopter crashes within the past decade and the increasing interest in helicopter crash survivability have stressed the need for seating systems which do more than merely provide a support platform for the occupant. Recognizing that the seat can play an important role in increasing his survivability, energy absorption (E/A) systems have been developed which allow the seat to move through a controlled displacement relative to airframe structure during the imposition of crash forces. Theoretically, the occupant's acceleration and seat break-away failures are expected to diminish as the E/A's effectively stroke and limit seat and floor loads. However, controlling seat displacement and acceleration does not necessarily mean that the occupant will be afforded maximum protection against the crash environment. When considering the total seating system and compartment into which it must be integrated, it is apparent that his well-being depends primarily on the way his motion is controlled in the seat and relative to other surrounding structures.

Unfortunately, current harness type restraint systems do not effectively restrain the occupant since the combination of restraint slack, elasticity and body compression allow him to move downward and forward in the seat. During an eyeballs out crash, when he finally moves sufficiently to be coupled to his restraining system, high decelerative and strap loads are applied to his body as his velocity instantaneously decreases to the velocity of the seat. In transferring his kinetic energy to the restraint, localized strap loads are distributed to those areas covered by the harness. Under the influence of the acceleration, his head and neck hyperflex and begin to rotate rapidly forward until forcibly stopped, either by muscular involvement or direct contact between his mandible and sternum.

This report describes a newly developed inflatable restraint which automatically compensates for any slack in the system, pretensioning the occupant in the seat during the initial phase of a crash. The results of a testing program to demonstrate system feasibility and determine loading distribution is discussed, and plans for more advanced prototype testing using humans are described.

SUMMARY OF RESULTS

The inflatable body and head restraint (IBHR) was tested on NADC's horizontal accelerator in two phases. The first phase was to determine if the use of the IBHR would result in improved protection to the wearer. The second phase was to determine if the system could be activated at the onset of a crash and effectively restrain the occupant.

During phase one, the restraint was statically inflated with air before the sled run. In phase two, the restraint was inflated by a solid propellant gas generator which was activated by a "g" sensitive crash sensor mounted on the sled.

Results of the statically inflated tests showed lower belt loads and lower head and chest accelerations with the inflated restraint as compared with an

uninflated restraint. The dynamic inflation tests proved that the system could inflate automatically during the crash pulse and produce loadings on the dummy which were comparable to the statically inflated test results.

Concern that the temperature of the inflator might be too high for wearer comfort were allayed. While the temperature was not measured directly, a check immediately after firing indicated that the area around the inflator was not hot enough to cause burns or serious discomfort to the wearer.

CONCLUSION

The tests show that an automatically inflatable restraint is feasible and provides increased crash protection over the conventional restraint.

The porous airbag material used in the manufacture of some bladders seems to be a good candidate for further experimentation. This material possesses good strength and abrasion resistance and is designed for storage in a confined space without deterioration. The porous material allows controlled escape of the gas from the bladder after the crash and puts slack back into the system. This allows ease in unbuckling the restraint to facilitate egress from the wreckage.

RECOMMENDATIONS

1. Proceed to optimize the subsystems and integrate them into a complete workable system. This includes:

- Modifying the gas generator for more rapid gas production and improvement of squib firing safety.

- Development of a multidirectional crash sensor specifically tailored for the helicopter crash environment.

- Selecting the optimum inflation bladder material with emphasis on strength, weight, durability and performance.

- Choosing the best techniques for fabricating the bladders to decrease packaging bulk and manufacturing cost.

- Development of suitable attachment and adjustment hardware to allow donning and removal of the restraint.

- Devising a method of packaging the bladder so that it is not cumbersome to wear in its stored position while offering protection against damage and abrasion.

2. Conduct a test and evaluation program on the modified design including:

- A form and fit evaluation

- Dynamic 30G test on the NADC horizontal accelerator

- Human subject testing on the horizontal accelerator up to the limits of safe testing

3. Obtain the necessary reliability information on all parts needed to determine the reliability of the entire system.

4. Formulate an integrated logistic support plan which will assure the effective and economical support of the restraint system for its life cycle.

5. Qualify the gas generator and squib for service use.

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BACKGROUND

Shortly after man's earliest aircraft flights, some sort of restraint was devised to keep the occupant attached to his seat or bench while offering some small protection in the event of a crash. The simplest restraint, a rope or belt anchored at either end to the aircraft structure and adjusted over the occupant's lower torso, soon gave way to an upper and lower body harness. By 1917, the restraint configuration had progressed to the point of sophistication where it consisted of two adjustable shoulder straps and two lower belt straps, terminating into a single point release located in the abdominal region of the pilot. Aside from the material and hardware improvements which have evolved since that time, present day restraints used in helicopters do not differ greatly from the configuration used in the 1917 Spad III aircraft. Certainly, there are many variations in the way that upper and lower straps can interface and effectively restrain and protect the occupant. Various degrees of restraint complexity have been covered in Snyder's [1] comprehensive review of experimental and practical restraint systems. However, no matter how effectively a restraint has been proven to act during an emergency, it is worthless if in a practical sense it is unacceptable for normal use. This has been the nub of the problem and the reason why there has been little movement away from the basic four-point shoulder-lap belt restraint used in military aircraft. Whenever ease of ingress or egress, comfort or body maneuverability are sacrificed for the sake of improved crashworthiness, it can be expected that any new restraint, no matter how effective, will be unacceptable to the user and soon rejected as cumbersome and restrictive for routine flight missions.

Although the conventional restraint's contribution to the survival and protection of vehicle occupants involved in crashes has been enormous, there are limitations which have long been recognized [2]. Perhaps its greatest failing involves improper adjustment, and as a consequence, ineffective positioning and restraint of the occupant in the seat at the onset of a crash so that control of his body and head is not maintained while crash forces are being limited and distributed. Unless the harness is properly positioned and tensioned, the occupant is likely to move as though unrestrained until all slack is taken out of the restraint. His acceleration, once he is coupled to his harness, will be determined by its initial slack, stretchability and the occupant's body compression. The importance of wearing tightly adjusted harnesses during a crash has been demonstrated experimentally [3]. Both German [4] and American [5]designers are presently working on the development of systems that automatically tension lap belts during the onset of crash. Pretensioning and positioning of the upper torso is equally important when ejecting from an aircraft. Ballistic inertia reels [6] have served this purpose on operational ejection seat systems for more than a decade. However, all inertia reels have the failing that when under load it is possible to withdraw 3 to 4 inches of webbing from the spool as the material packs down, layer upon layer [7], thereby contributing to the overall system slack.

Most current restraints do not use a tie-down strap to keep the lap belt from "riding-up" over the pelvis. The negative-G strap, as used by the British [8], has reduced the incidence of crewmember submarining and lower back involvement because it keeps the lower restraint properly positioned over the pelvic girdle. User acceptance does not appear to be a problem if the strap is properly located and angled between the crewman's thighs.

The problems associated with controlling or restraining head motion and limiting both linear and angular acceleration are most perplexing to the designer of a restraint providing maximum protection. Although many approaches have been suggested and tried, none have gotten beyond the experimental or very limited use stage [9, 10]. Once again, the basic problem has been user acceptance, since any mechanism or device which limits the freedom of head motion or becomes uncomfortable because of weight, fit or attachment is immediately rejected. Yet head injury and concussion, because of hyperflexion and rotation [11], is a major problem which cannot be dismissed nor de-emphasized because of past failures to develop a practical means of reducing head trauma.

The distribution of crash loads to the occupant has been another designer concern. The restraint webbing bearing against body structure should be optimized to reduce concentrated loads on the torso and possible skeletal fractures [12]. Yet, it is no less important that the webbing be comfortable to wear and not a source of thermal build-up. Another factor, but of less importance, is that its weight should be minimized. In considering the distribution of loads to larger segments of the body, the selection of a particular width may prove ineffective if it has the tendency to curl-up when the occupant is seated [13]. The 3-inch-wide lap belt used widely by the military in aircraft fixed seating systems does exhibit this characteristic after the seated crewmemember has leaned forward several times.

All of the problems outlined above, have been addressed in the development of the inflatable body and head restraint (IBHR). When the system is activated and inflated, it will automatically remove any slack in the occupant restraint, tightening around the crewmember's torso to the extent that he is forcibly moved against the supporting interior surfaces of the bucket. An inflatable appendage of the upper restraint is used to resist forward angular displacement of the occupant's head during impact, minimizing whiplash and restraining his mandible from striking his sternum. As the crewman moves into the inflatable (under the impetus of his own acceleration), restraint loads are distributed over large segments of his upper and lower torso by virtue of the large areas covered by the inflatable bags captured between his body and an outer restraint webbing. Increased body force has the effect of flattening the inflatable, thereby increasing the torso area covered and further distributing crash loads. A tie-down strap is used to anchor the lap belt in place and reduce the probability of submarining. A distinct advantage of the system is that it does not take away restraint protection if it fails to inflate since the outer harness attached to the inflatables is almost identical to present day restraint configurations, and in fact represents an improvement with the fifth tie-down strap.

INFLATABLE RESTRAINT SYSTEM

The restraint system has been designed using the air bag concept of enveloping the seated occupant with a gas-filled inflatable to prevent fatalities and reduce occupant injuries during a potentially survivable crash. Unlike the automotive air bag which is a passive device remotely located from the occupant, the inflatable restraint is worn in a fashion similar to the present day crewman harness. The concept is based on the approach taken by Granig [14] for an automotive three-point safety belt. In all respects, his harness appears to resemble the conventional restraint until it inflates during the imposition of a crash. In a like manner, the

inflatable restraint intended for military fixed seating systems, has been configured essentially the same as the harness currently being used in helicopters and other fixed seat aircraft. These harnesses usually consist of 1-3/4-inch wide shoulder straps and 3-inch wide lap belt straps connected together to a central fitting. Operation of the fitting releases all straps simultaneously. Both shoulder straps are joined directly behind the occupant's neck and terminate into an inertia reel mounted onto the seat back. The ends of the lap belt are anchored to the lower rear portion of the bucket.

The inflatable restraint system is comprised of three major subsystems: (1) the bladder/restraint, (2) the inflator and (3) the crash sensor (figure 1). It has been designed so that in its stowed position it appears somewhat like the conventional harness. When unfurled, the bladder / restraint is revealed as shown in figure 2.

The porous bladder material is neoprene-coated nylon. The degree of porosity is determined by the tightness of the ripstop weave and the amount of neoprene used in the coating. Each of the lap and shoulder bladders meet at a common junction so that when gas is introduced into the inflatable, it will distribute itself equally into each of the bladder sections.

A harness fabricated from polyester webbing is attached to the outside surfaces of the bladder complex by an adhesive. Its purpose is to transfer the major crash loads into the seat rather than using the fabric for this purpose.

The gas producer is a cylindrical pyrotechnic inflator manufactured by Thiokol Corporation for this specialized system (figure 3). It is inserted and located within the bag material at the junction of the upper and lower harness and held in place by an adhesive applied to the top and bottom surfaces of the inflator and to the material it contacts. Dimensionally, the generator is 3 inches in diameter by 1 inch deep.

The major components of the gas generator include the ignition system, the gas generant and combustion chamber, the cooling filter, and the chamber with diffuser. The inflator is initiated by an electrical pulse to a squib which ignites a charge of ignition powder contained in a perforated tube sealed with foil. The igniter generates heat and glowing particles which are expelled through the perforations in the tubular chamber to ignite the surrounding gas generant. The gas generant, in the form of pellets, is contained in the tubular combustion chamber. It is composed of a nitrogen-producing compound based on sodium azide.

The combustion chamber contains internal screens for gas generant retention and solids filtering and contains the nozzle orifices for ballistic control. The gases leaving the combustion chamber pass through the cooling-filter module and exit through the diffuser. The cooling-filter contains a wire screen pack to remove solids and mechanically cool the gases. The components are confined in a two-part chamber which comprises the pressure vessel and is joined by threads. The gas exit holes are designed to uniformly diffuse the gas and keep the inflator thrust neutral. A nontoxic gas, mainly composed of nitrogen, fills each of the restraint bladders to a pressure of 4 psi in less than 25 msec after initiation.

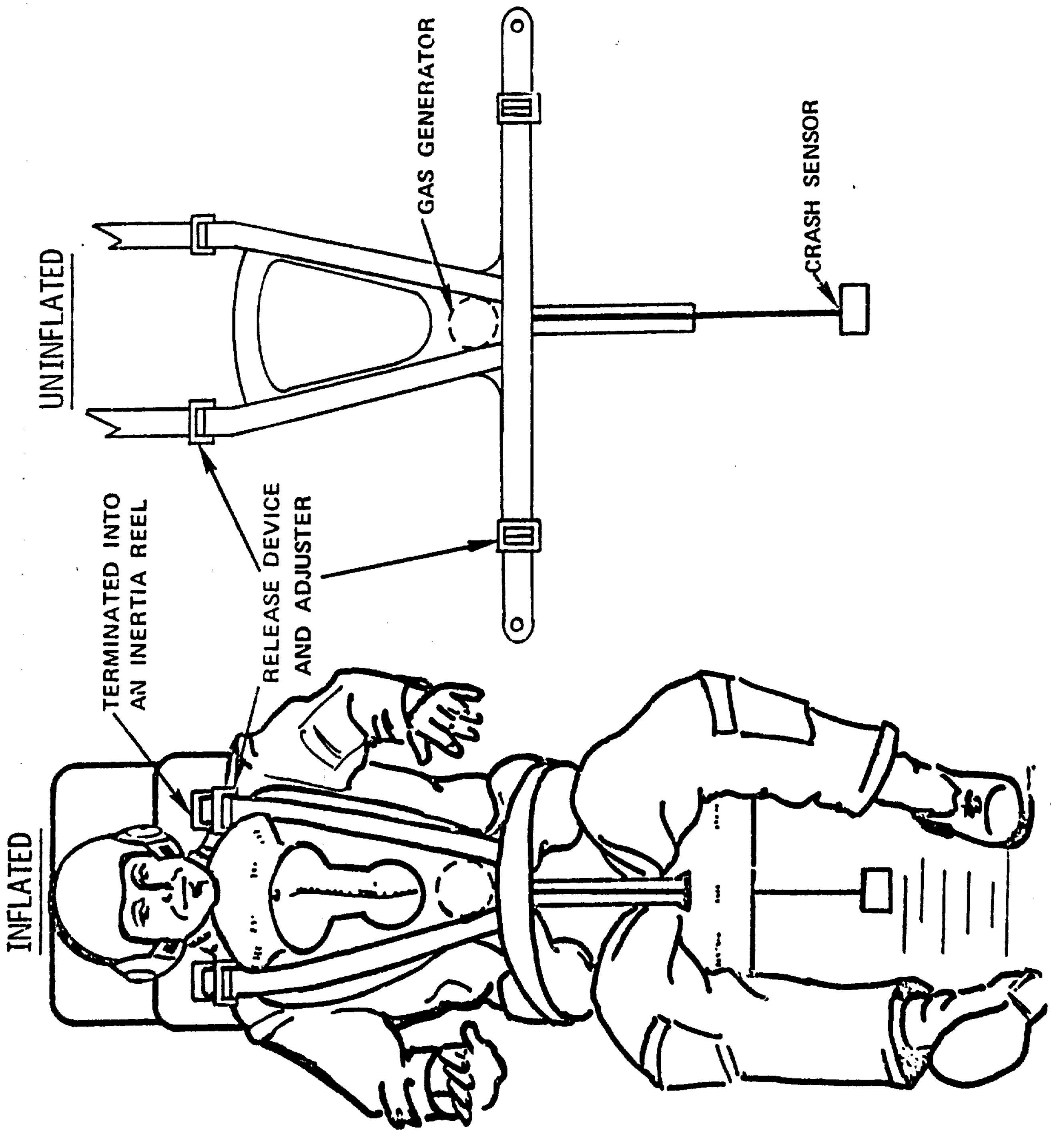


Figure 1 - Inflatable Body and Head Restraint

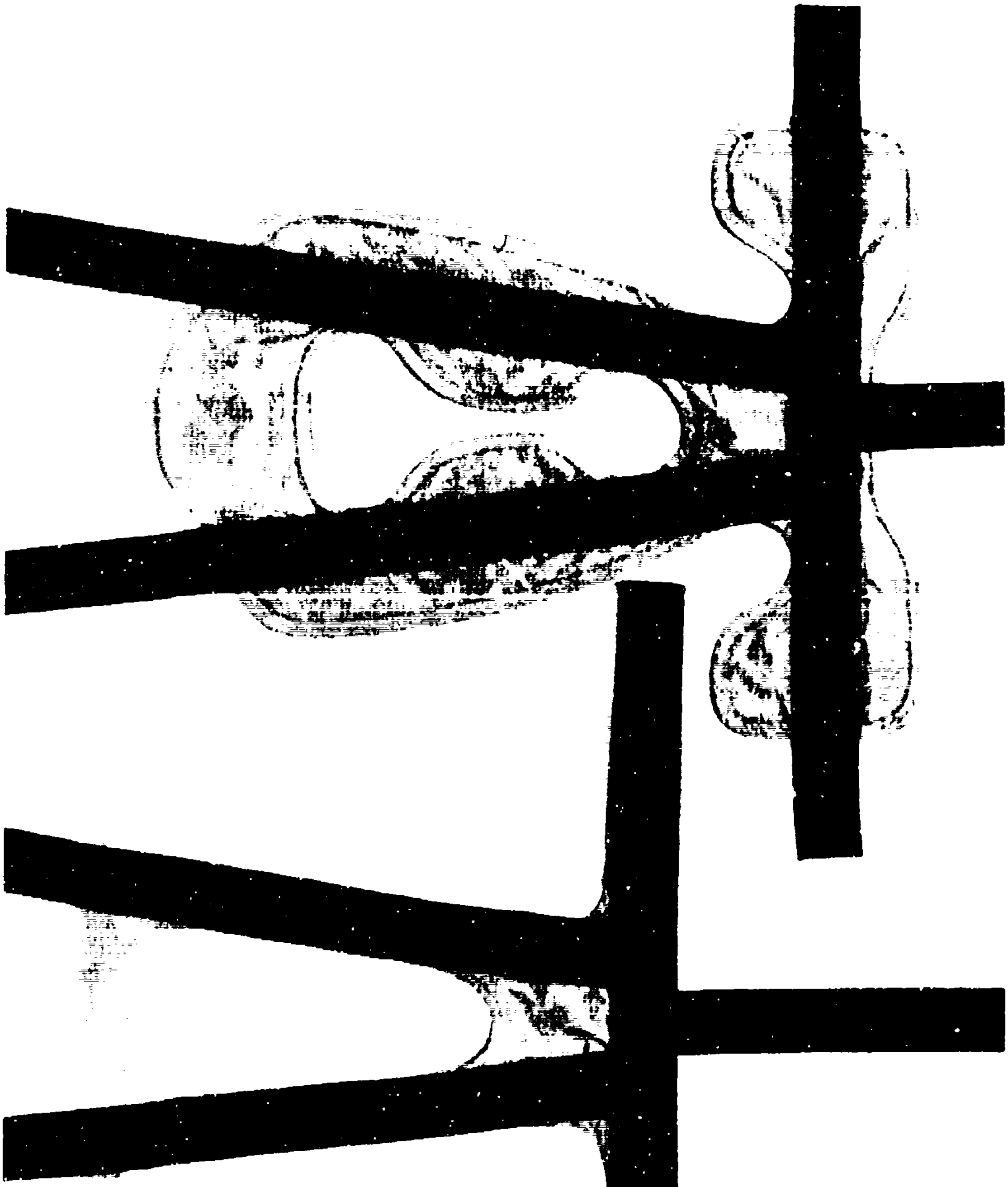


Figure 2 - Comparison of Inflatable Restraint in Stowed Position (left), Unfurled (right)

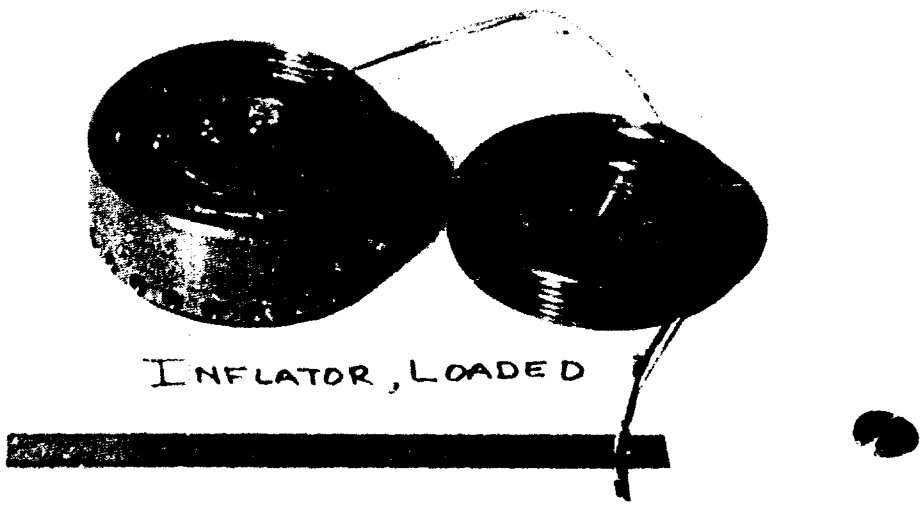


Figure 3 - Thiokol Corporation Pyrotechnic Inflator

A pair of wires attached to the electrical squib are withdrawn from the bag and directed by way of the tie-down strap and seat to a remotely located crash sensor mounted on the floor of the aircraft. The sensor, manufactured by TECHNAR, Inc., is an acceleration switch using the Rolamite Concept [15]. It has been selected because of its ability to act as an integrator of acceleration-time. Upon sensor closure, 3.5 amps of current is supplied either through aircraft electrical service or by a discharging capacitor to the electrical squib. The sensor is set to close at an energy level of 5 G for 11 msec. Inflation of the restraint occurs within the initial 30 msec after the sensor closes. As the occupant's body moves into the bladders, its pressure increases while it is being compressed by the torso against the outer straps offering further resistance to his movement into the restraint. The material, being semipermeable then allows the gas to escape so that in less than 0.1 second after initiation the pressure has decreased to its original 3 psi with the bladder continuing to deflate with time. Should a secondary impact occur, the uninflated restraint is still positioned around the occupant offering protection against further decelerative forces.

STATIC PREINFLATED TESTING

Before proceeding to tests involving automatic inflation of the restraint system, a series of experiments were performed to determine what level of pressure produced by the gas generator could be tolerated without physiological complications and still effectively remove slack from the system. Once the pressure was determined, generators could be manufactured to this requirement.

Restraint systems were fabricated to the configuration shown in figure 2. A nonporous neoprene-coated nylon material was used for the construction of the bladders so that the restraint could be preinflated using an externally regulated air source. Several live subjects, occupying a test seat and wearing the restraint adjusted to fit snugly, were exposed to incrementally increasing pressures until they felt uncomfortably squeezed between the expanded bladders and the seat back. Each subject described the system as completely restraining his upper and lower torso to the extent that only his extremities were free to move. Lateral motion was also greatly curtailed. A peak pressure of 4 psi was measured on one subject at the time that he indicated his maximum voluntary exposure level was reached. Two other subjects were exposed to 3.5 psi before signaling a halt to further increases. The restraint was completely loosened on the subjects without relieving the pressure being monitored. At this time, a nominal pressure reading of 1.7 psi was obtained. Obviously, this pressure level is dependent upon the adjusted tightness of the restraint before being inflated.

Tests were repeated with the upper restraint adjusted to 2 inches of slack and the lap belt fitted snugly against the torso, then again with 2 inches of slack in the upper restraint and 1 inch of slack in the lap belt. Under both of these conditions when 4 psi of air was introduced into the bladders, all slack was removed and the occupants experienced complete restraint without feeling uncomfortable. They described the tightness as exceeding the degree of tightness usually attained when adjusting conventional harness straps by tugging on the webbing ends. When the restraint was loosened after each adjustment, pressure readings of 2.5 and

3.2 psi were measured respectively. Based on the above tests, gas generators capable of producing 4 psi were purchased for later full system testing.

PREINFLATED DYNAMIC TESTS

A series of dynamic tests were next conducted on the restraint using the Naval Air Development Center's Horizontal Accelerator (figure 4). The purpose of these tests was to determine the effectiveness of the inflatable when compared with itself in the uninflated state. The Accelerator is characterized as a "quick start" device which applies an acceleration pulse to the test load at the beginning of the test sequence. Acceleration simulating a crash occurs when a pneumatically powered ram is triggered to rapidly push a sled, upon which the test load is mounted, along a pair of machined rails. Acceleration simulating a crash therefore occurs while the sled moves from an initial condition of rest to maximum velocity at the end of the ram stroke. Upon separation from the ram, the sled slides along the rails, slowing gradually due to friction and drag until it is gently stopped by an arresting cable.

The shape of the acceleration time pulses applied to the sled and test load are shown in figure 5. Two levels of acceleration and velocity were used throughout the entire program. A peak acceleration of 15 G with a velocity change of 25 ft/sec, and an acceleration of 30 G and 50 ft./sec. velocity were selected as typifying aircraft crash pulses. The latter is representative of the 95th percentile potentially survivable accident [16], and has been adopted by the Army and Navy as the maximum severity test condition in the longitudinal direction.

A test seat and Alderson VIP-50A anthropomorphic dummy weighing 170 lb. was installed on the Accelerator sled (figure 6) so that it would be exposed to a (-Gx) deceleration (eyeballs out). A tri-axial cluster of Endevco Model 2262 piezo-resistive accelerometers was mounted in the head measuring Ax, Ay and Az and a biaxial cluster in the chest to measure acceleration in the Ax and Az axis. During several tests, a special head bracket containing CEC 4-202 accelerometers was mounted on the dummy to measure angular acceleration using the Bendixen technique [17]. Restraint system reaction loads were measured with GSE force sensors installed on the two shoulder and lap belts directly beyond the bladders. These sensors convert axial forces in the webbing into normal forces on the rods which comprise each unit. A CEC Model 4-326 pressure transducer was used to monitor internal bladder pressure.

The dynamic sled runs were conducted with the same three variations in harness slack adjustment used during the static preinflated tests. In each case, the restraint system was first tested uninflated and then inflated to 4 psi after it had been adjusted to the proper amount of slack. Figure 7 gives a comparison of the uninflated and inflated shoulder and lap belt loads for the three slack conditions when the sled was fired at 15 G. It is apparent that for all these conditions the inflatable has reduced the strap loads; the smallest reduction occurring when the upper and lower harness are tightly positioned around the dummy and the greatest improvement when there is the largest amount of slack in the system. Resultant chest acceleration likewise diminished when the system was inflated. A typical load versus time comparison is shown in figure 8. As evident from this curve, the reduction in peak loads is primarily a function of the restraint becoming effective earlier in the crash pulse. Strap loads and occupant acceleration begin to increase gradually with a much lower sustained rate of onset, maximum load being reached approximately 0.01 second later in the crash. In comparison, the uninflated restraint does not become effective until more than 0.05 second

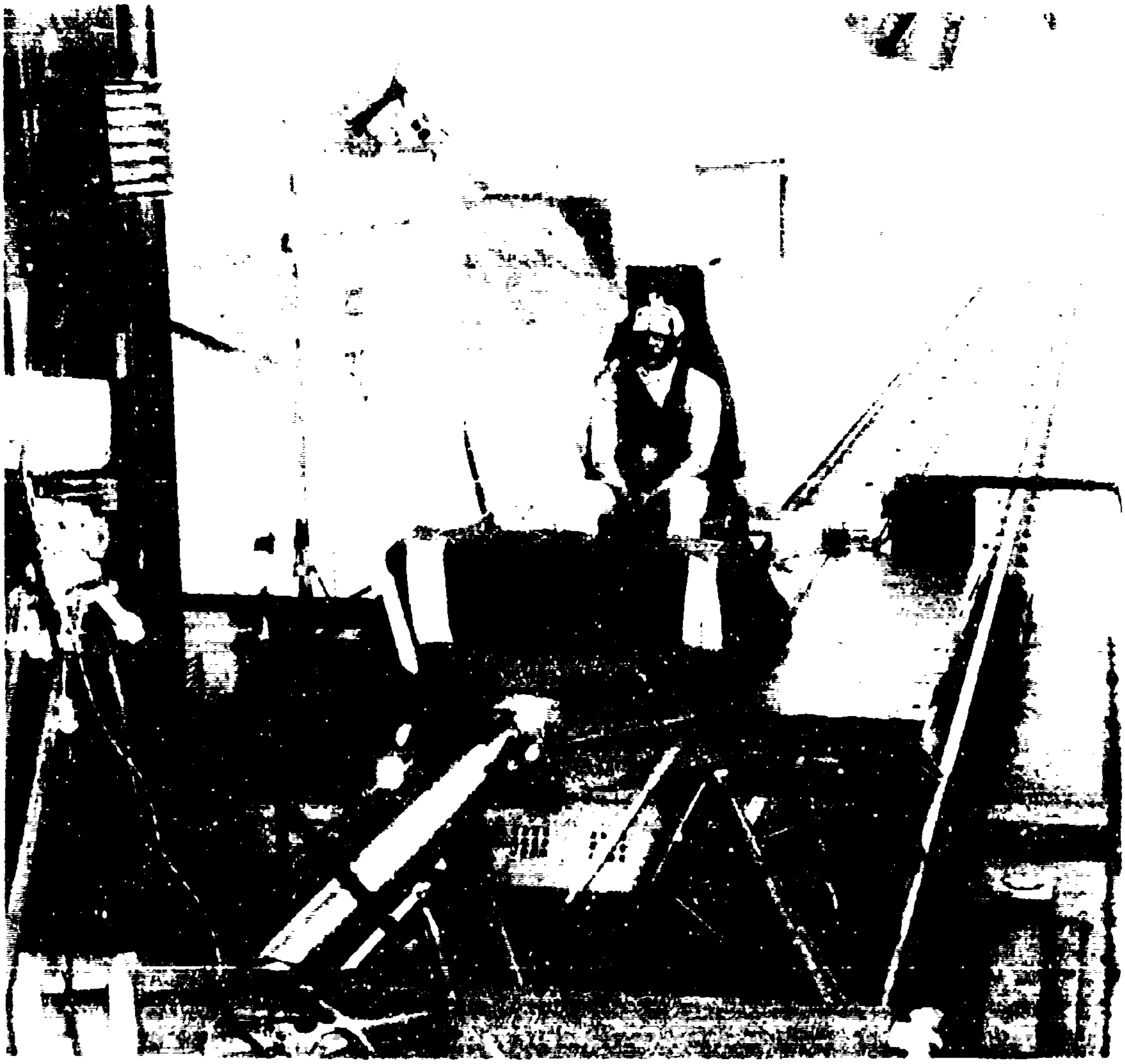


Figure 4 - Naval Air Development Center Horizontal Accelerator

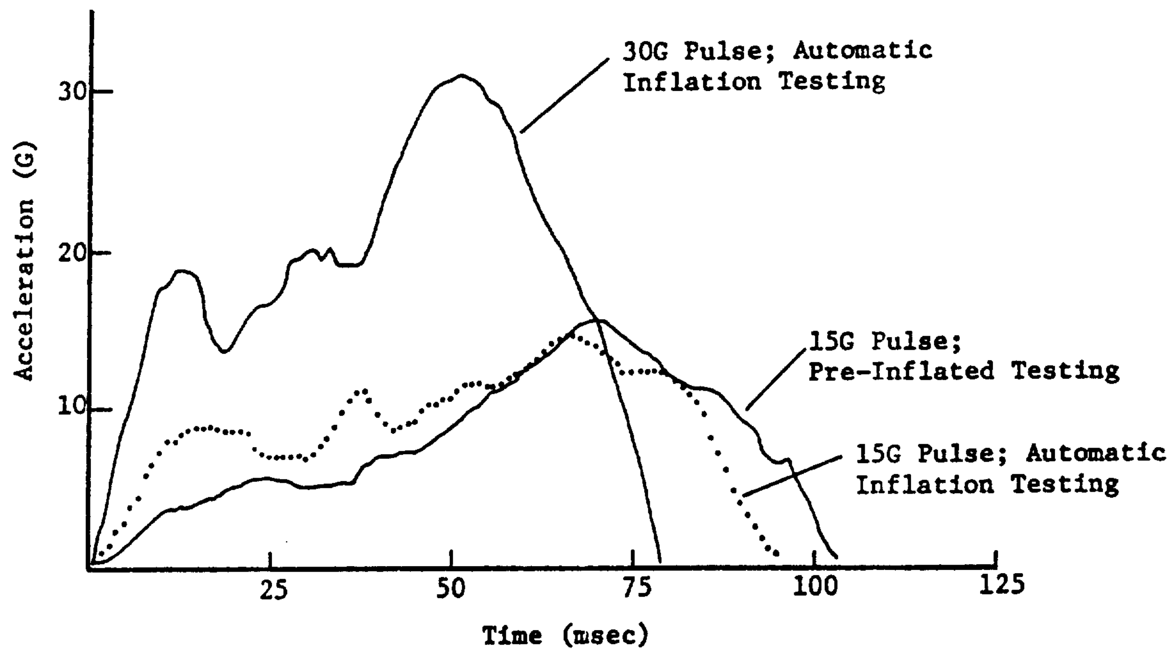


Figure 5 - Input Accelerations Applied to the Sled During Dynamic Testing

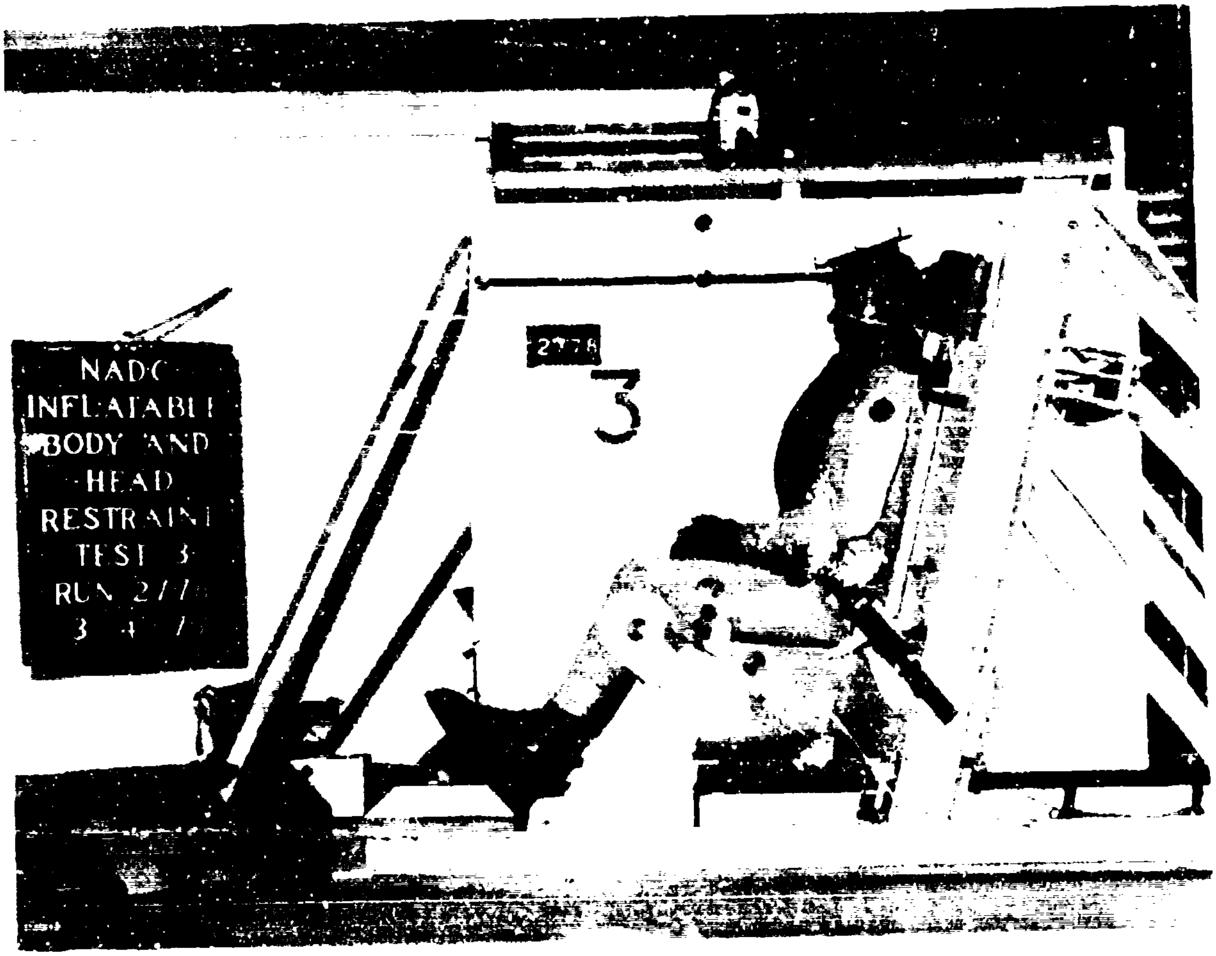


Figure 6 - Pretest Position of Dummy With Restraint System Preinflated

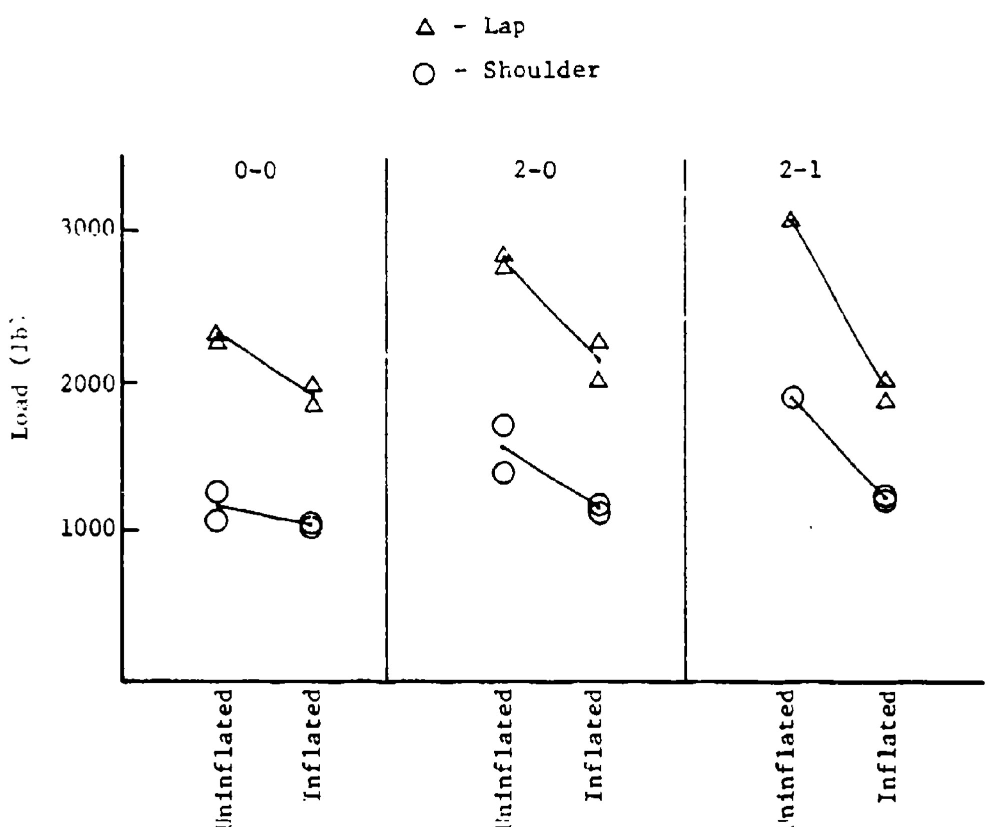


Figure 7 - Trend Curve Showing Reduction of Restraint Loads With Inflation for Three Slack Conditions

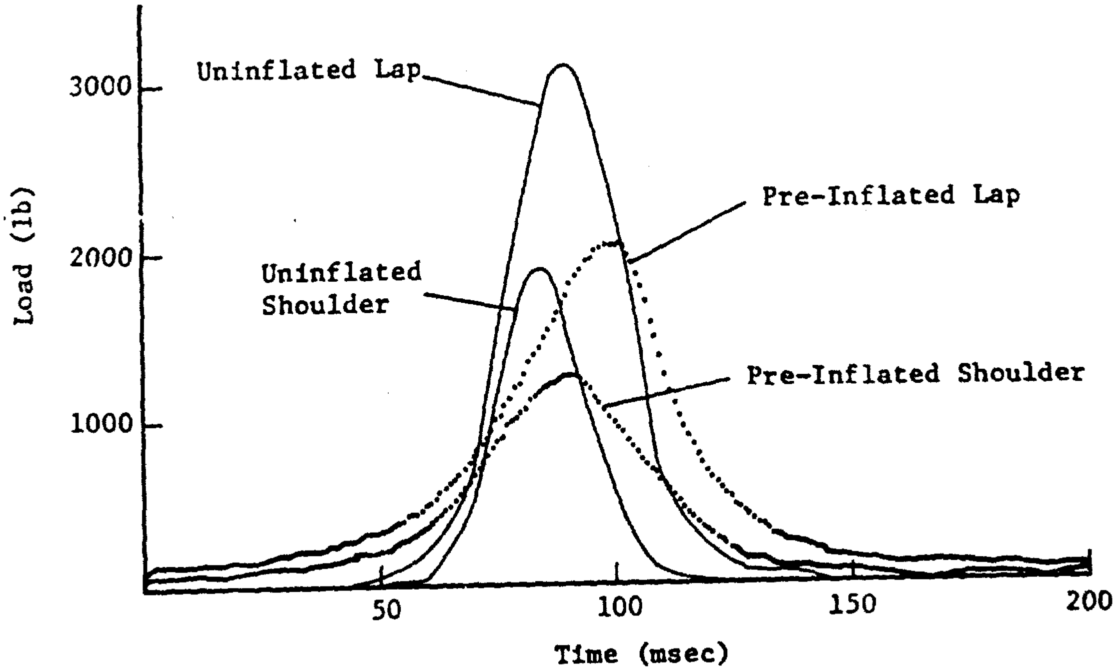


Figure 8 - Uninflated Vs. Preinflated Restraint With 2-In. Shoulder and 1-In. Lap Belt Slack (2-1); at 15G

into the crash. At this time, the relative velocity between the seat and occupant has increased to 11.4 ft/sec.

The prepositioned appendage of the bladder restraint mounted under the occupant's chin cogently reduces the forward angular velocity of his head. Figure 9 shows the comparison of two conditions of slack. As the slack increases, the angular velocity and acceleration of the head become more pronounced because of the increased relative velocity between the occupant and the seat at the time that his torso is coupled to the restraint. With the occupant's body finally restrained, higher forces are generated so that the head-neck complex is momentarily left behind, whipping around and forward. The (2-1) slack condition produced a maximum angular velocity of 40.1 rad/sec and a corresponding angular acceleration of 3286 rad/sec^2. When inflated and subjected to the identical test conditions, angular velocity and acceleration reduced to 17.6 rad/sec and 474 rad/sec^2, respectively. Less dramatic but significantly reduced values of angular velocity and acceleration were also obtained for the (0-0) slack condition. Head angular velocity reduced from 23.3 to 12.1 rad/sec while the acceleration changed from 1148 to 334 rad/sec.

Unfortunately, when a 30-G accelerator test was attempted with the preinflated restraint, a corner of the bladder material tore because of concentrated stress. The bladder and load carrying straps were redesigned to relieve this stress point; the new configuration was then tested in the automatic mode.

AUTOMATICALLY INFLATED DYNAMIC TESTS

Six complete automatically inflating restraints were fabricated using a new configuration consisting of minor dimensional modification to the bladder and the addition of two short overlaying straps to redirect the load path. Several of the bladders were fabricated with a nonporous nylon/neoprene material and the remainder using a heavier porous nylon fabric with a 1/2-inch ripstop weave. The latter material was chosen because of its superior tensile and bursting strength, which would be needed for higher G exposure tests, and its pressure releasing capability which would reduce occupant rebound.

Before exposing the full system to dynamic tests, a static inflation was conducted to verify that the gas generator would produce the proper inflating pressure. As purchased from Thiokol Corporation, each generator could be dismantled and propellant added or removed to change its performance. A generator was fired with the restraint tightly fitted to the seated dummy in the same manner that static preinflated tests were performed using human volunteers. A pressure of 5.7 psi was produced within the bladders. Combined shoulder and lap belt loads of 220 and 351 lb were recorded, respectively. Since all previous testing had been done with air pressure of approximately 4 psi, propellant was removed to reduce the pressure level. A second test firing produced a 4.3 psi bladder pressure and combined shoulder and lap belt loads of 182 and 275 lb. Subsequent dynamic tests were performed with generators using the same amount of propellant.

Several dynamic tests were made to establish the time delays associated with sensor closure, squib detonation and gas generation. The test firings, using the same crash input pulse as the preinflated system runs, disclosed that the sensor took 0.036 second to close. Initial generator gas pressure was recorded several

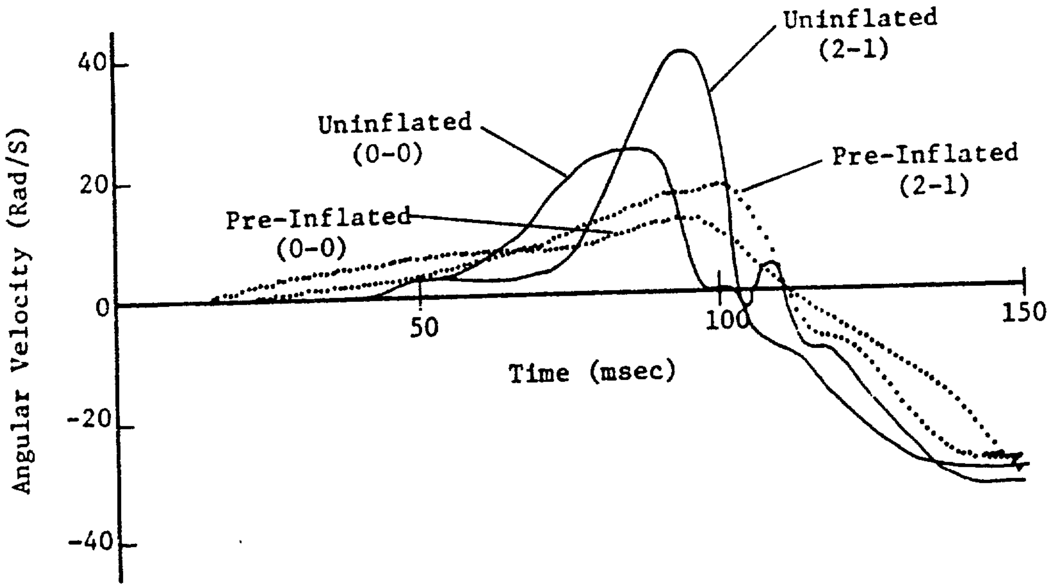


Figure 9 - Comparison of Head Angular Velocity for the Uninflated and Preinflated Restraint With Two Extreme Conditions of Slack

milliseconds later, with the peak pressure being reached in 0.025 second. It became apparent that the total time delay would substantially reduce the effectiveness of the inflatable since its essential feature is that it couples the occupant to the restraint as quickly as possible after the crash. The delay could be shortened by altering the inhibitors used with the propellant, but in the interest of proceeding with the tests, a modified input crash pulse was chosen as the easier approach (figure 4). By increasing the G rate of onset without changing the velocity under the curve, the sensor closed 0.019 second after the start of the crash pulse, a reduction of approximately 0.017 second from previous tests.

A series of full system dynamic tests were made under the identical three conditions of slack used previously. The uninflated restraint system was not tested again for the 15-G crash pulse since those tests had been conducted when the preinflated restraint was evaluated. It should be noted however, that the uninflated and automatically inflated restraints were exposed to inputs which varied to the degree shown in figure 4. The comparison is still considered valid since the increase in energy during the initial portion of the curve used with the automatic restraint should not bias the load results in favor of the inflatable.

The results of the 15-G tests were similar to the preinflated runs. In all cases, strap loop loads reduced with the inflatable. Comparison load curves for the two extreme conditions of slack are shown in figures 10 and 11 and peak values are recorded in table I. In each case, the dummy starts loading the inflatable restraint at 0.030 second, approximately 20 milliseconds ahead of the uninflated system. Resultant peak chest acceleration, likewise decreased; dropping from 26.6 to 19.9 G for the tightly adjusted restraint and from 44.0 G to 29.1 G for the loose system. Angular acceleration and velocity of the head was not obtained because of an instrumentation malfunction.

Table I

Peak Strap Loads for Three Slack Conditions in the Inflated and Uninflated Modes at 15 G

	Peak Shoulder Loads		Peak Lap Loads	
Slack Condition	Uninflated	Inflated	Uninflated	Inflated
0 - 0	1263	984	2332	1916
2 - 0	1717	1094	2860	2026
2 - 1	1881	1263	3089	2103

At the conclusion of the 15-G tests, the nonporous bladder system was removed from the dummy and a porous bladder restraint substituted in its place. With the restraint tightly adjusted to the dummy, two 30-G test firings were made, first with the bladder uninflated and then automatically inflating. The results, shown in figure 12, indicate little difference between both conditions. This is to be expected since when tightly adjusted, the uninflated restraint begins loading at about 0.025 second. The inflatable needs approximately the same amount of time

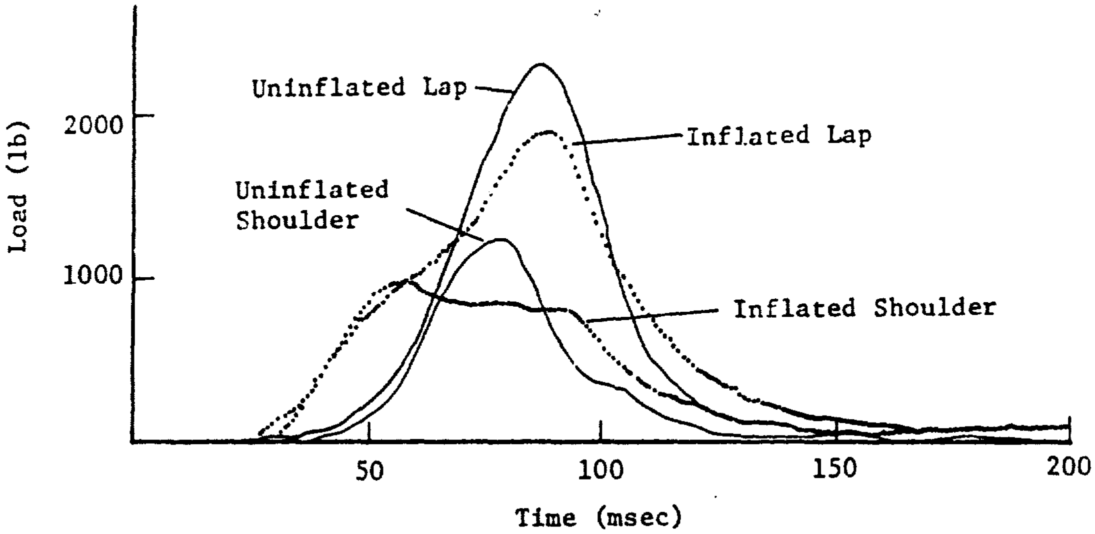


Figure 10 - Uninflated Vs. Automatically Inflated Restraint, Tightly Adjusted (0-0); at 15G

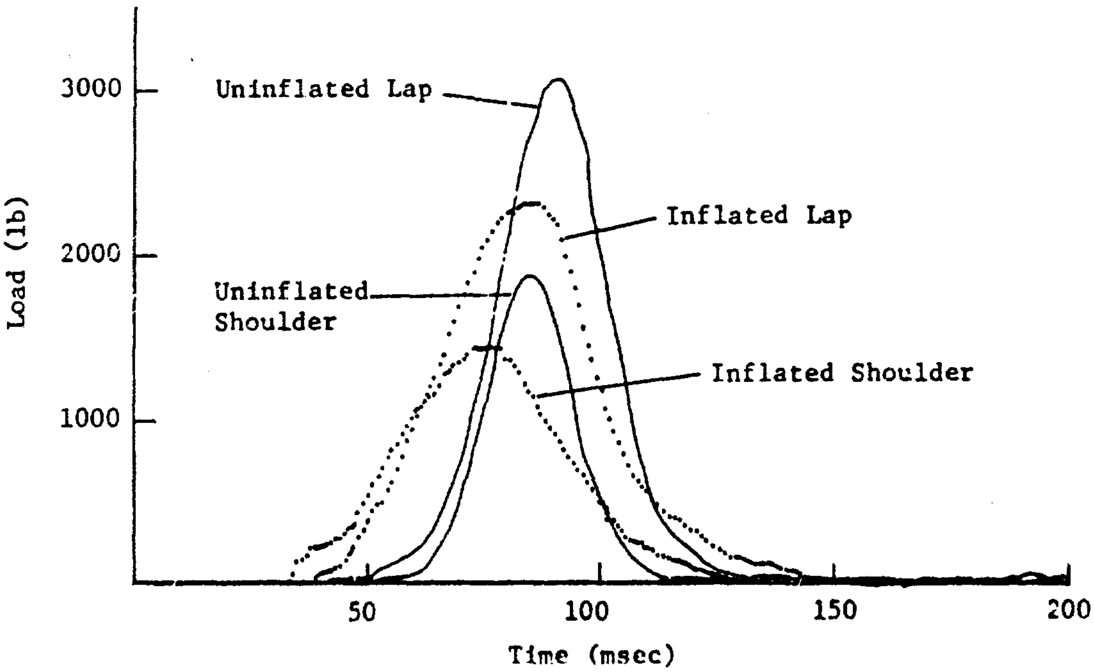


Figure 11 - Uninflated Vs. Automatically Inflated Restraint With 2-In. Shoulder and 1-In. Lap Belt Slack (2-1); at 15G

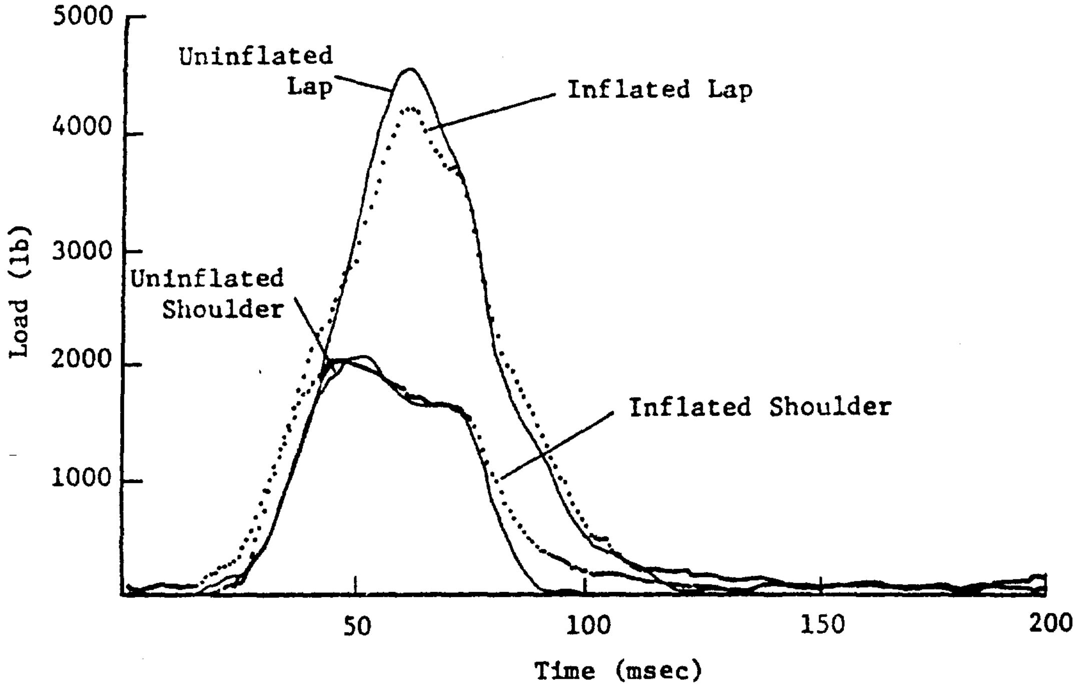


Figure 12 - Uninflated Vs. Automatically Inflated Restraint, Tightly Adjusted (0-0); at 30G

before gas pressure is produced and directed into the bladders. Measurement of resultant chest acceleration for both restraints was 48.6 and 47.3, respectively. Head angular acceleration and velocity was not measured because of instrumentation difficulties.

Due to a shortage of inflators, the (2-0) slack test was eliminated in favor of the (2-1) condition. Figure 13 shows the load curves for the inflated and uninflated condition. The results of the test indicated that the inflated restraint reduced the peak shoulder load from 2[illegible]5 to 2078 lb., peak lap load from 4670 to 4008 lb., maximum resultant head acceleration from 102.5 to 67.8 G's, and maximum resultant chest acceleration from 70.6 to 47.6 G's.

During the movement of the dummy into the inflatable restraint system, pressure increased in the bladders, reaching a peak at the time that maximum strap loads were recorded. When tested at 15 G, an internal peak pressure averaging 16 psi was measured. At 30 G, a peak pressure of 23 psi was produced. Bursting failure of a restraint fabricated with the nonporous material occurred once during the program after being used several times for inflation tests. No failures were experienced with the porous fabric.

NASA LANGLEY DROP TEST

The IBHR was tested in an experimental crash drop of a CH47 helicopter at the NASA Langley Research Center. One purpose of the experiment was to compare the effectiveness of the IBHR with a conventional helicopter restraint. In addition, the experiment would demonstrate that the inflatable system is capable of functioning under "real world" conditions and at the same time obtain the CH-47 "crash signature," i.e., the magnitude and duration of the crash pulse as necessary information for the crash sensor development.

To obtain the comparative data, two similar 95th percentile dummies were restrained in the pilot and copilot seat by the IBHR and a conventional system, respectively. Each dummy was clothed in white thermal underwear and wore a naval aviator's helmet. No slack was allowed in either restraint. The original equipped seats and cushions were used and no attempt was made to improve the strength of the seat or its support structure.

Each dummy had a triaxial accelerometer mounted in the chest cavity and each restraint had force transducers mounted on the webbing to measure loads on the lap belt and shoulder harness. In addition, a pressure transducer was used to measure the internal gas pressure of the inflatable system. Photographic coverage of the cockpit was achieved by two high-speed motion picture cameras equipped with wide-angle lenses.

The inflatable restraint system was essentially the same as that used on the dynamic sled tests. One notable exception was the use of a quicker acting squib installed in the gas generator to decrease inflation time. The generator was positioned, as before, inside the bladder of the inflatable restraint. A wire from the generator ran to a battery pack through a crash sensor switch. The Technar crash sensor was mounted on the floor in the rear cockpit area between both seats. A triaxial accelerometer was mounted at this same position to record the acceleration levels of the crash.

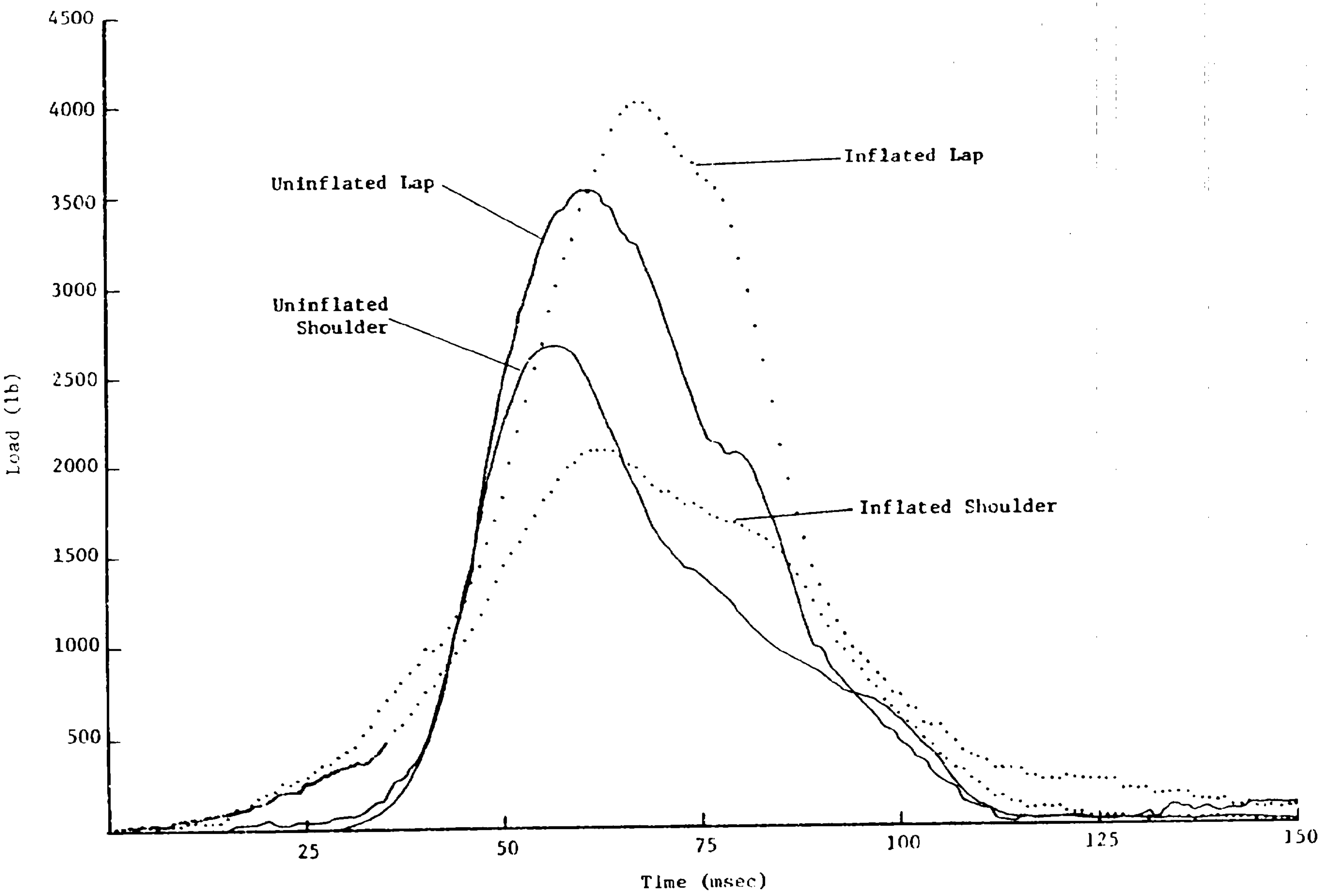


Figure 13 - Uninflated Vs. Automatically Inflated Restraint With 2-In. Shoulder and 1-In. Lap Belt Slack (2-1); at 30G

The helicopter was dropped from a height of 54 feet with a 5-degree nose-down attitude (figure 14), producing an impact resultant velocity of 50 ft/sec. This resultant velocity vector represents the 95th percentile potentially survivable helicopter crash pulse.

Review of the motion pictures revealed that the inflatable restraint system functioned properly during the crash. Although the seats were considerably deformed by the crash forces, the inflatable restraint was able to constrain the dummy in the pilot seat (figures 15 and 16). Unfortunately, the inertia reel on the copilot seat failed, releasing the shoulder straps which allowed the dummy to pitch forward in the seat. This inadvertent motion eliminated all chance for a meaningful comparison of the data collected from transducers on both dummies.

A summary of the restraint pressure, decelerations and restraint system loads measured during the drop test is presented in table II. The peak value and the time after impact that each occurred are also presented. Time response plots of the data summarized in this table are shown in figures 17 through 25. All data shown in these plots were filtered at 100 Hz.

Table II

Summary of Drop Test Data

Parameter	Peak Load (psi, G or lb.)	Time (msec)
IBHR Pressure	9.6	105
Floor Gx	19.0	68
Floor Gz	158.0	58
Pilot Chest Gx	12.6	81
Pilot Chest Gy	3.7	62
Pilot Chest Gz	15.9	55
Pilot Chest Resultant	19.2	106
Copilot Chest Gx	9.6	94
Copilot Chest Gy	6.0	105
Copilot Chest Gz	21.7	61
Copilot Chest Resultant	22.7	61
Pilot L. Shoulder	535	73
Pilot R. Shoulder	666	103
Pilot L. Hip	385	115
Pilot R. Hip	247	176
Copilot L. Shoulder	158	156
Copilot R. Shoulder	135	62
Copilot L. Hip	379	188
Copilot R. Hip	394	180

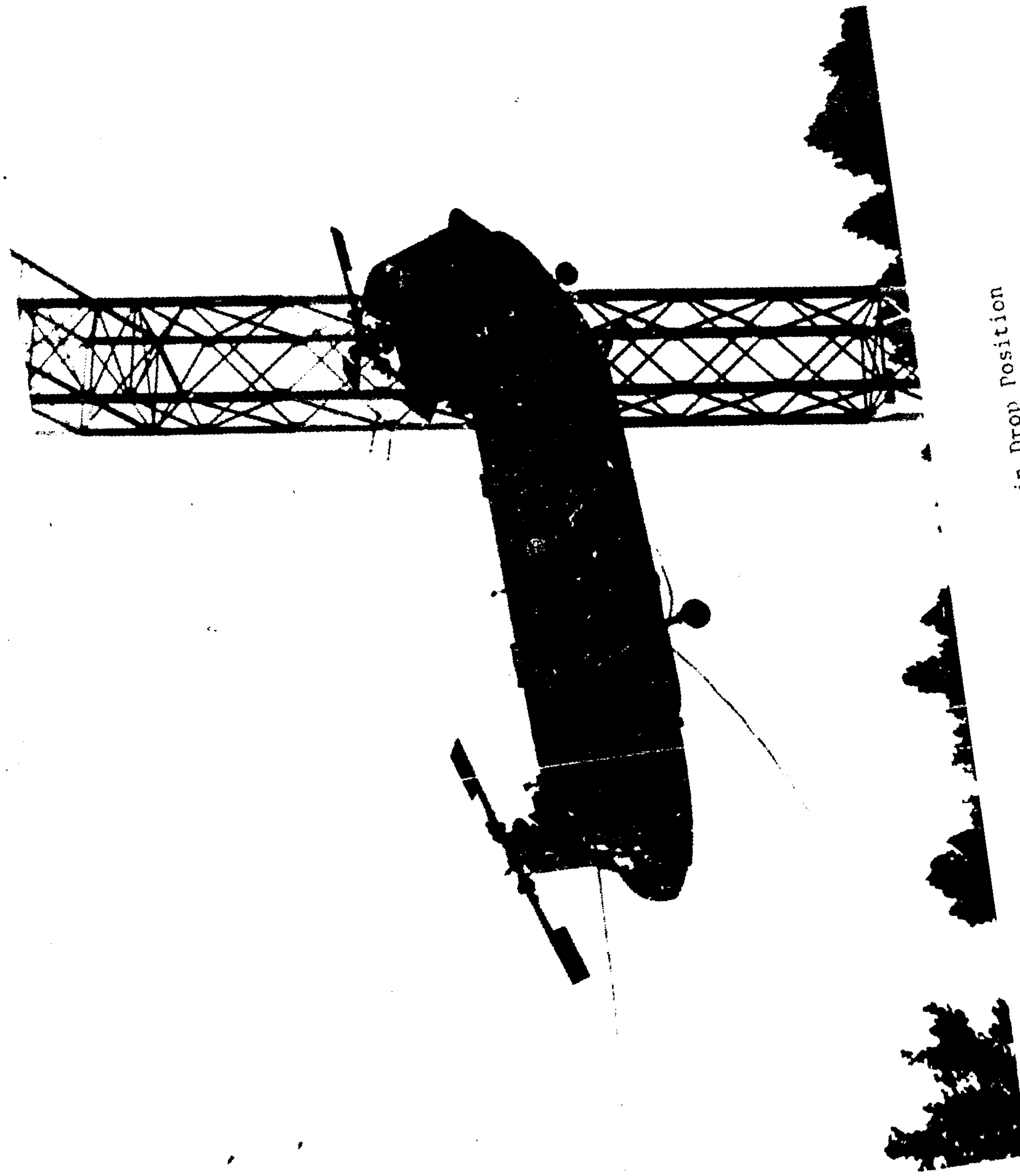


Figure 14 - CH47A Test Vehicle in Drop Position

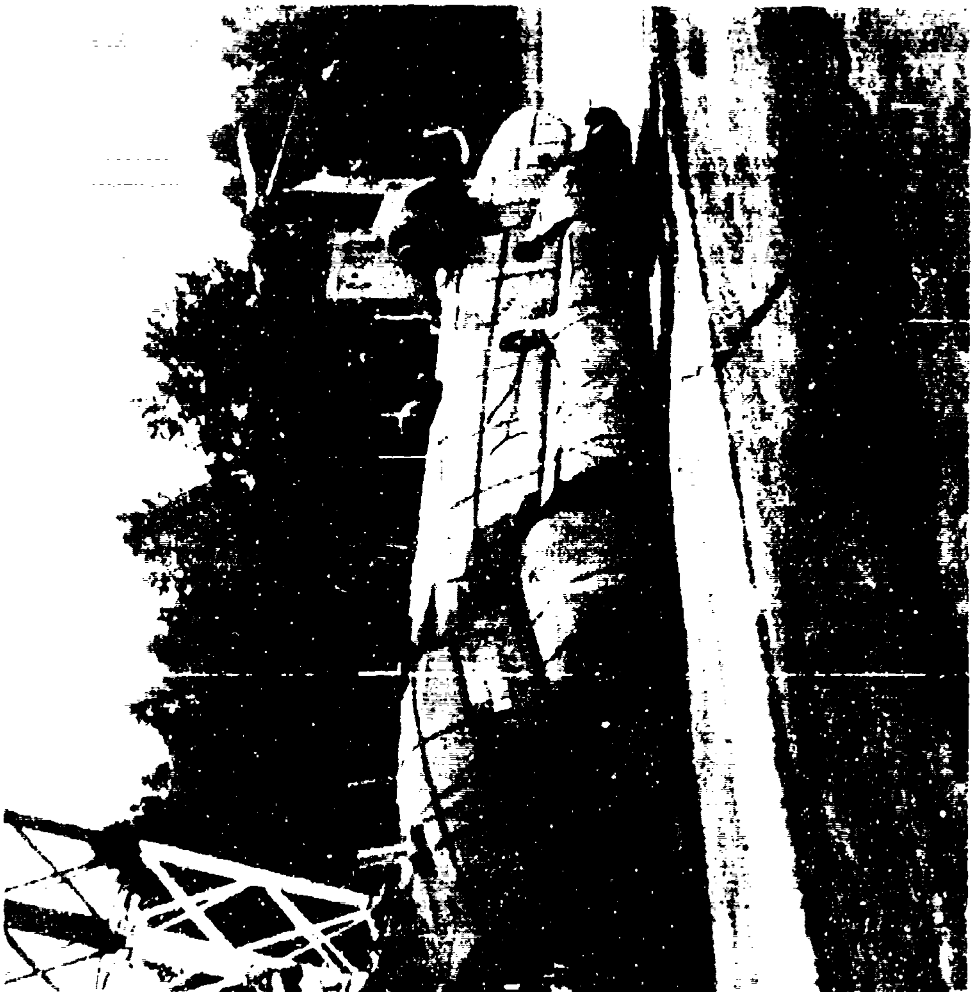


Figure 15 - CH47A Test Vehicle (Post-Test)

Figure 16 - Post-Test Cockpit Showing Crash Damage and Dummy Positions

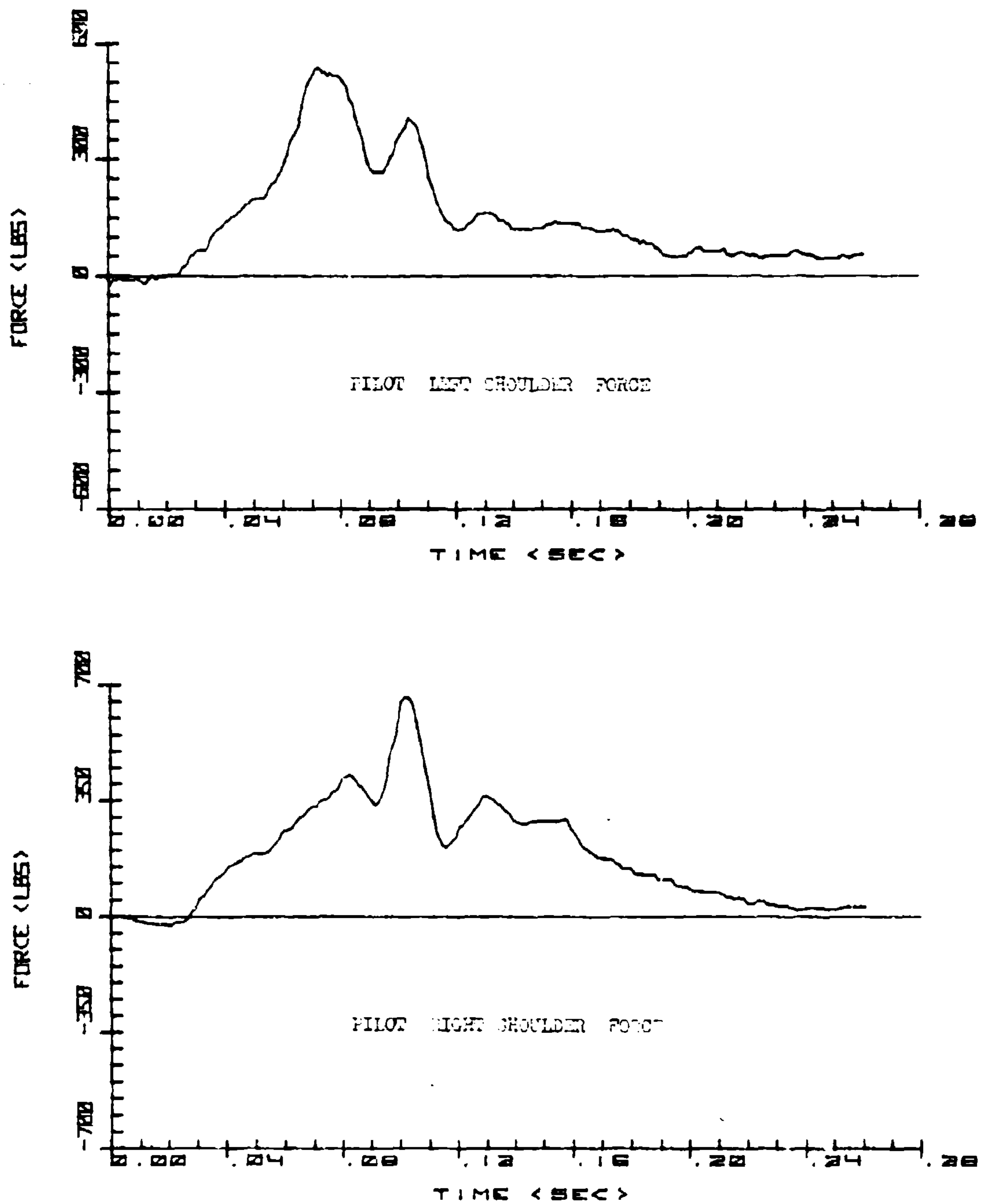
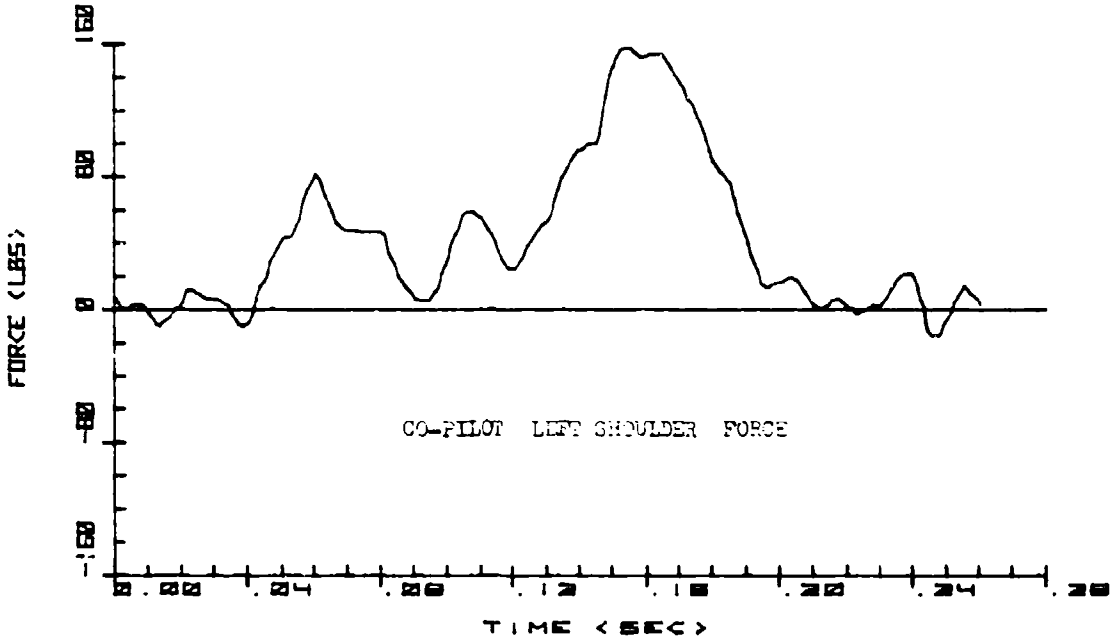


Figure 17 - Pilot Restraint Shoulder Loads Vs. Time



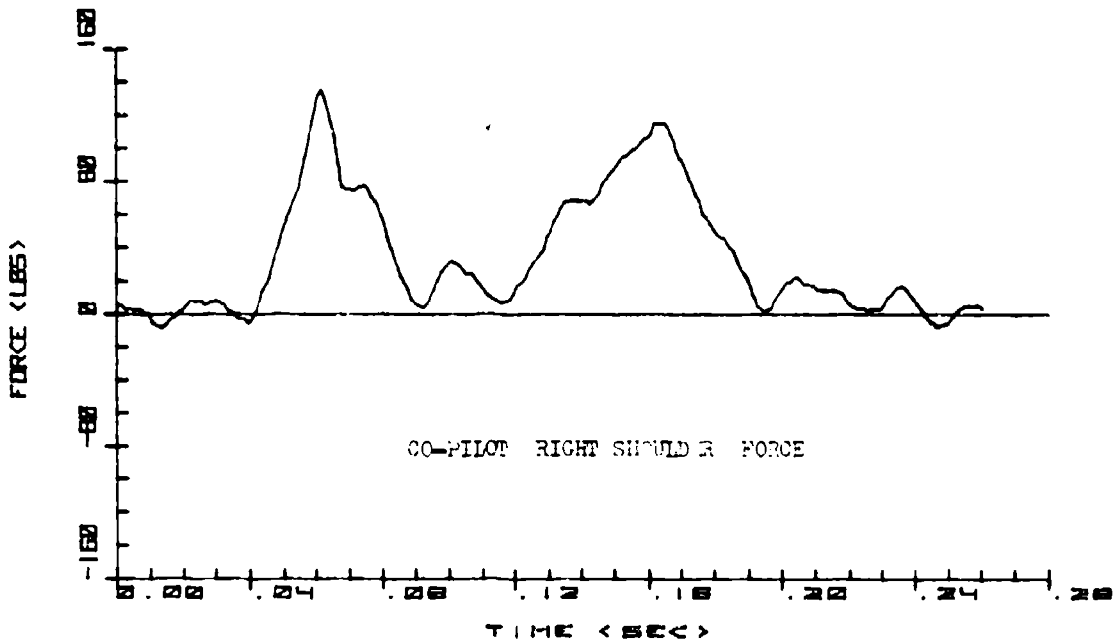


Figure 18 - Copilot Restraint Shoulder Loads Vs. Time

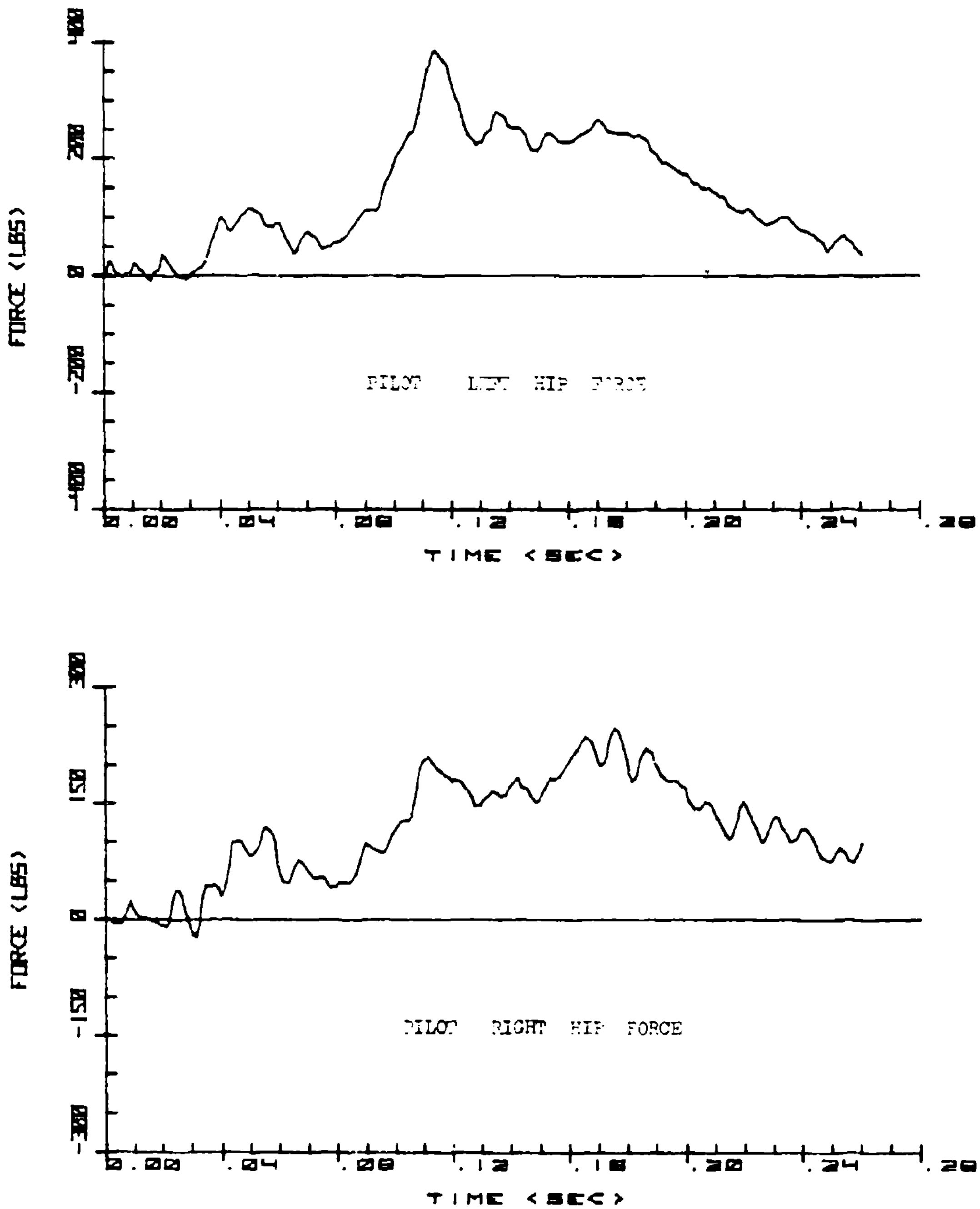


Figure 19 - Pilot Restraint Hip Loads Vs. Time

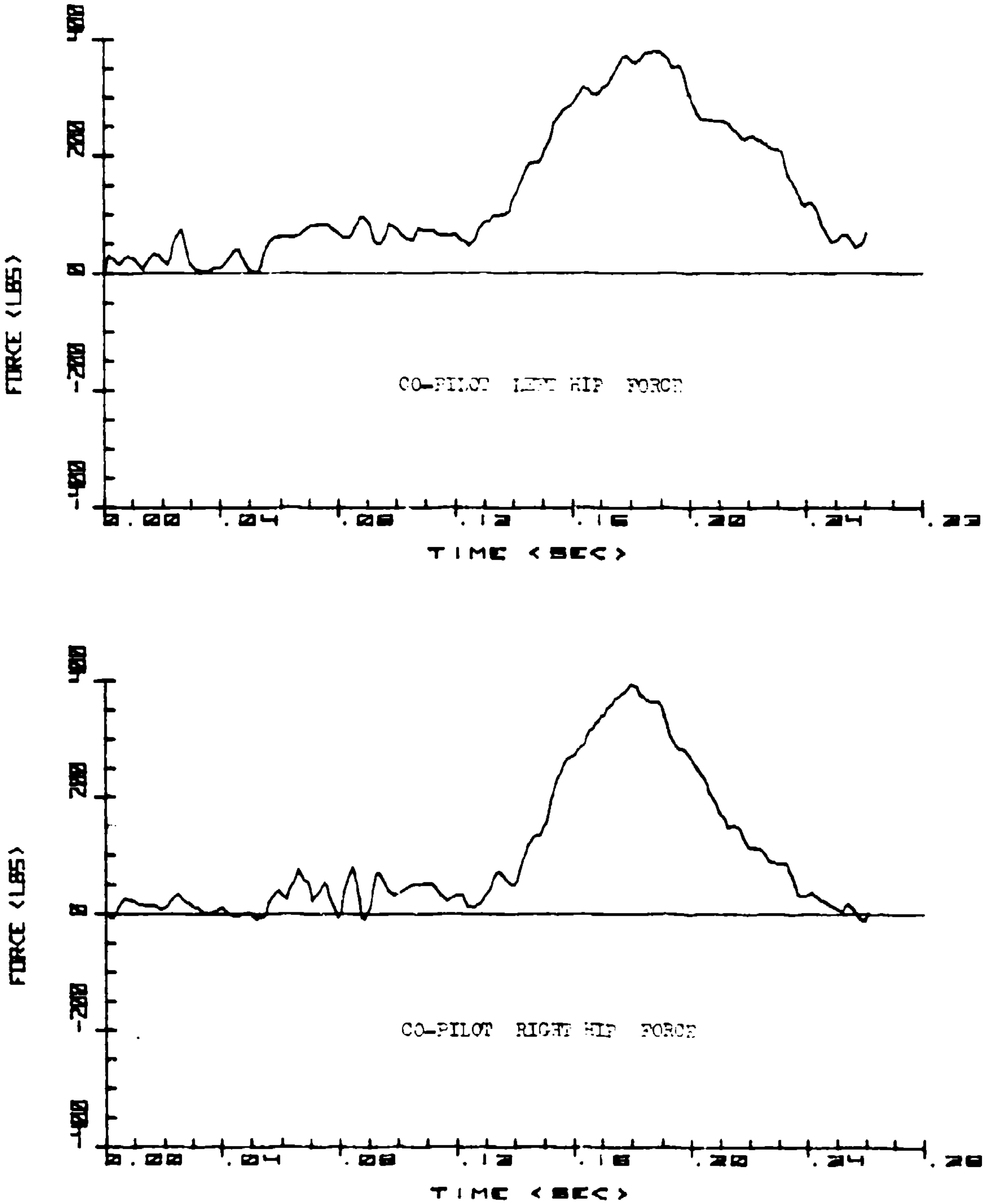


Figure 20 - Copilot Restraint Hip Loads Vs. Time

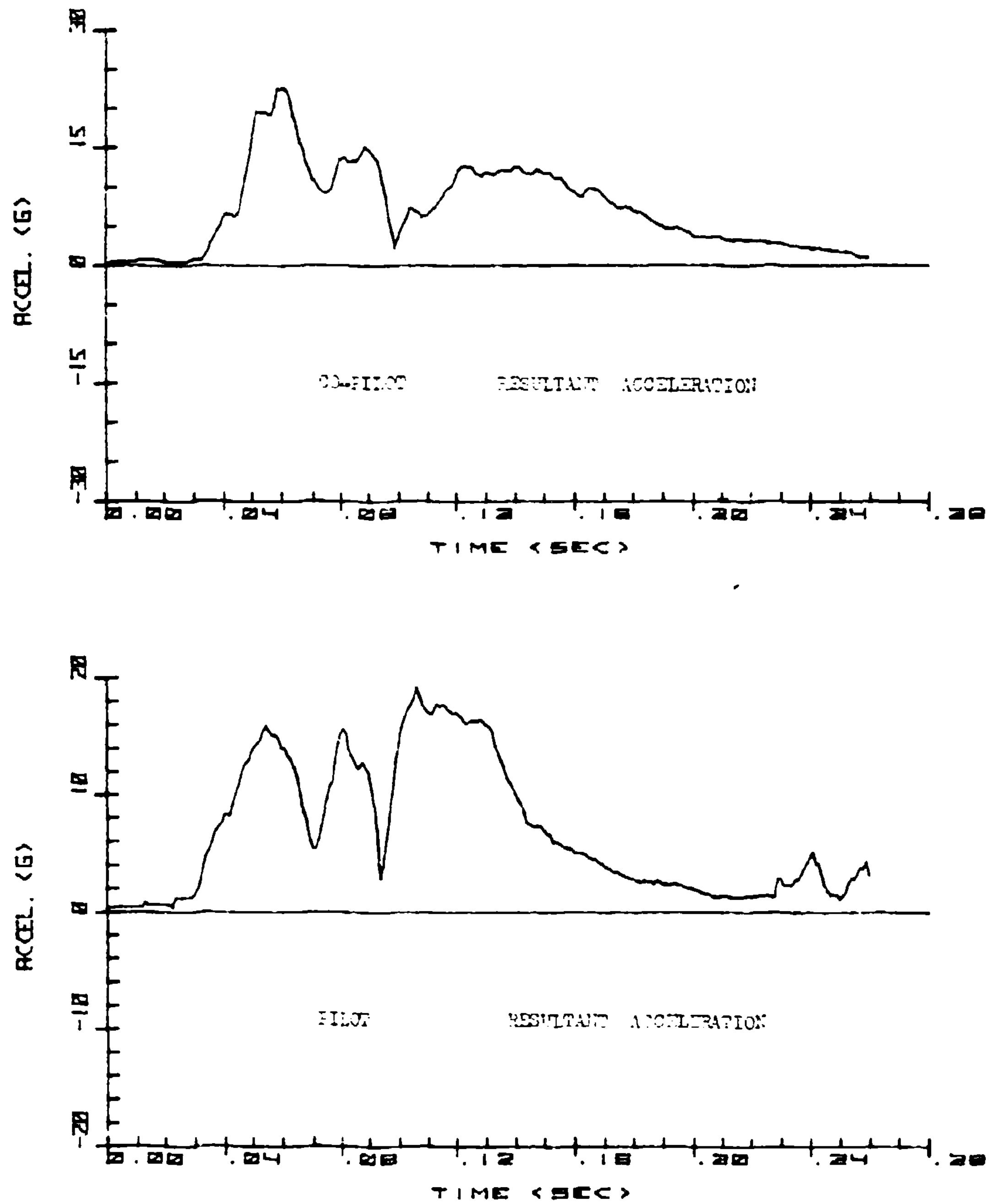


Figure 21 - Pilot and Copilot Resultant Chest Acceleration Vs. Time

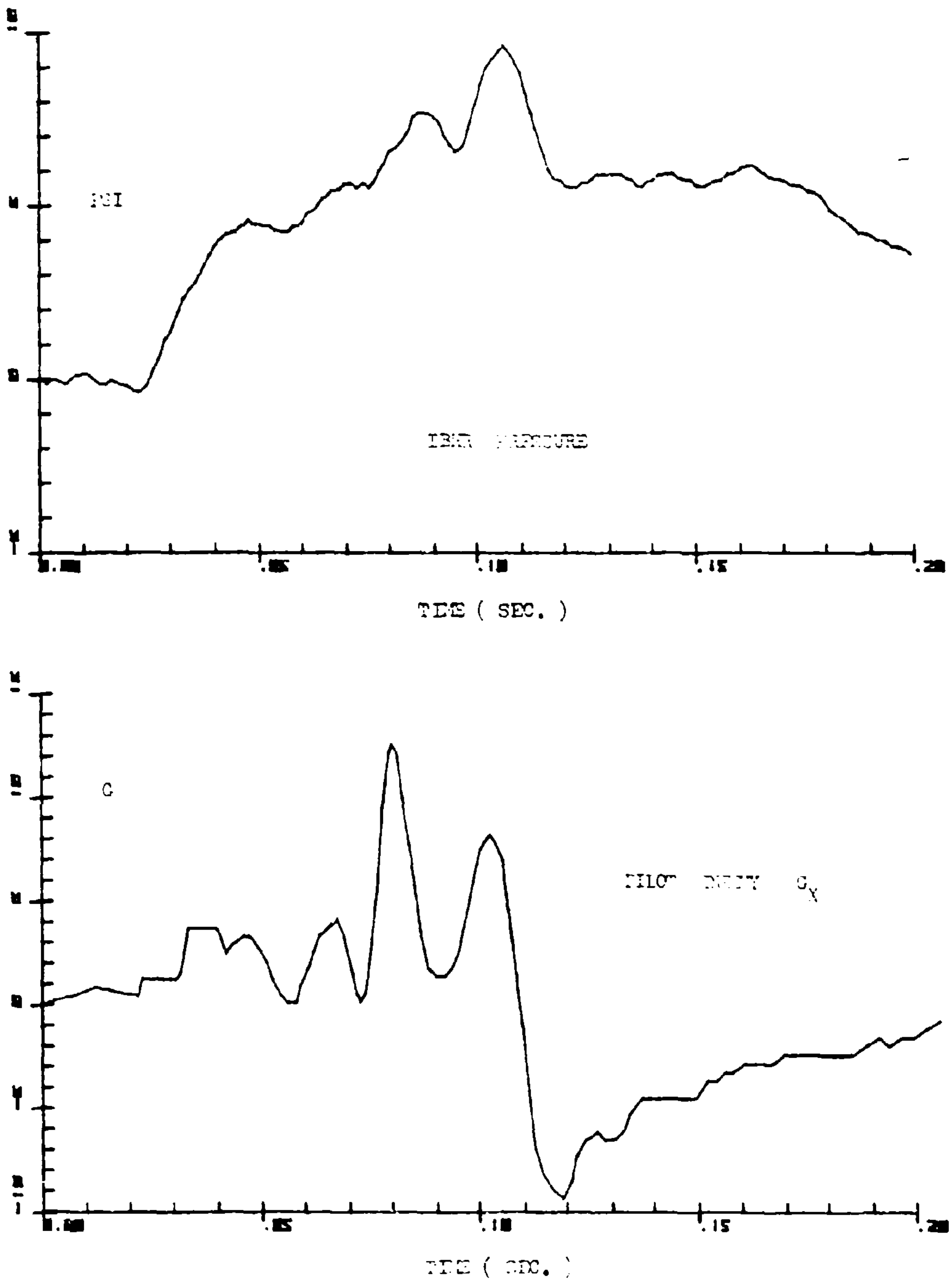
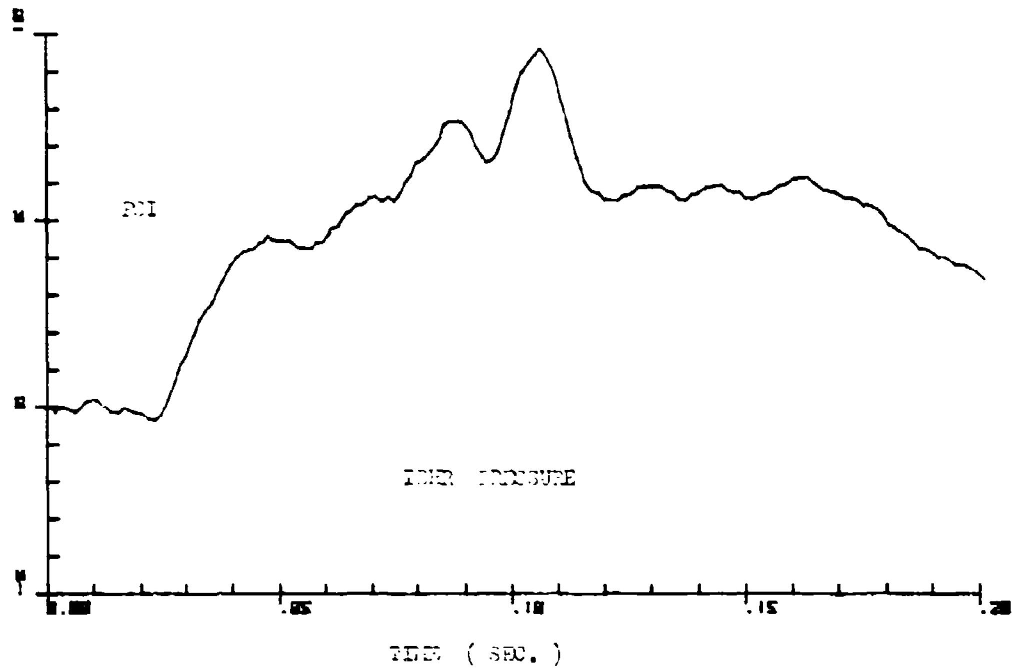


Figure 22 - Pilot Horizontal Chest Acceleration and Bladder Pressure Vs. Time



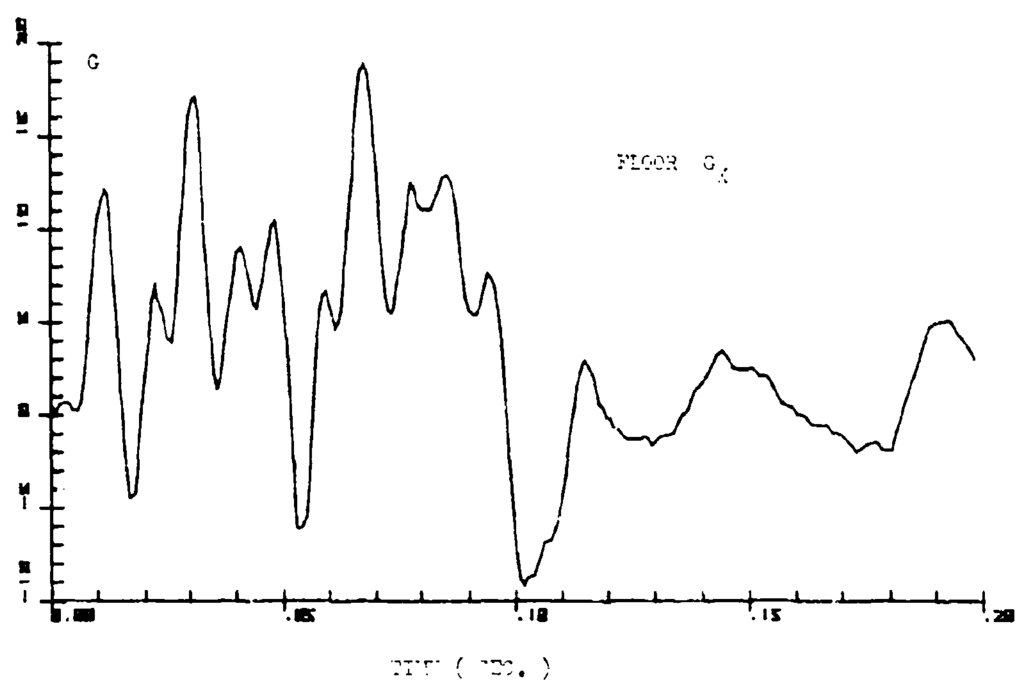


Figure 25 - Aircraft Horizontal Acceleration and Bladder Pressure Vs. Time

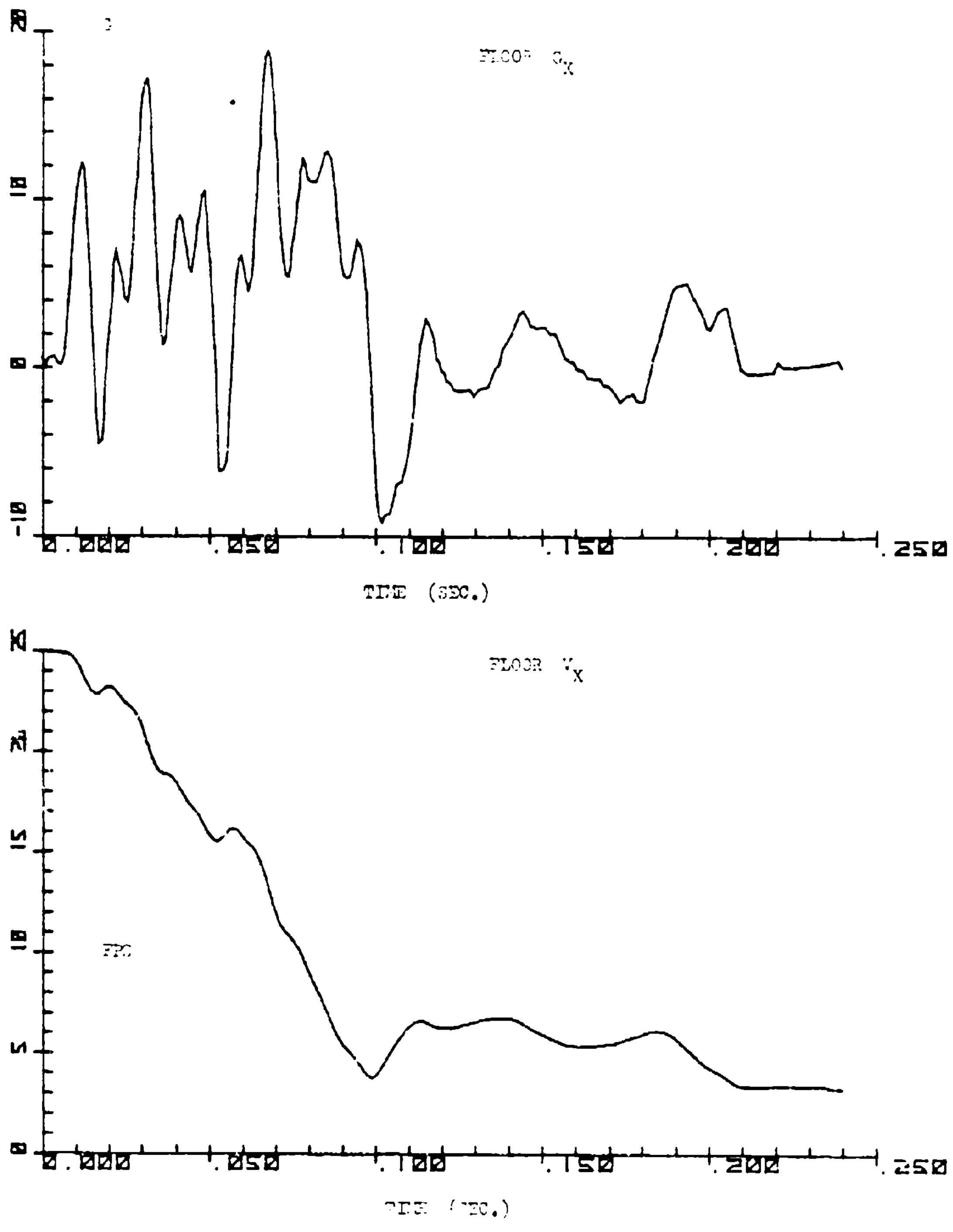


Figure 24 - Aircraft Horizontal Acceleration and Velocity Vs. Time

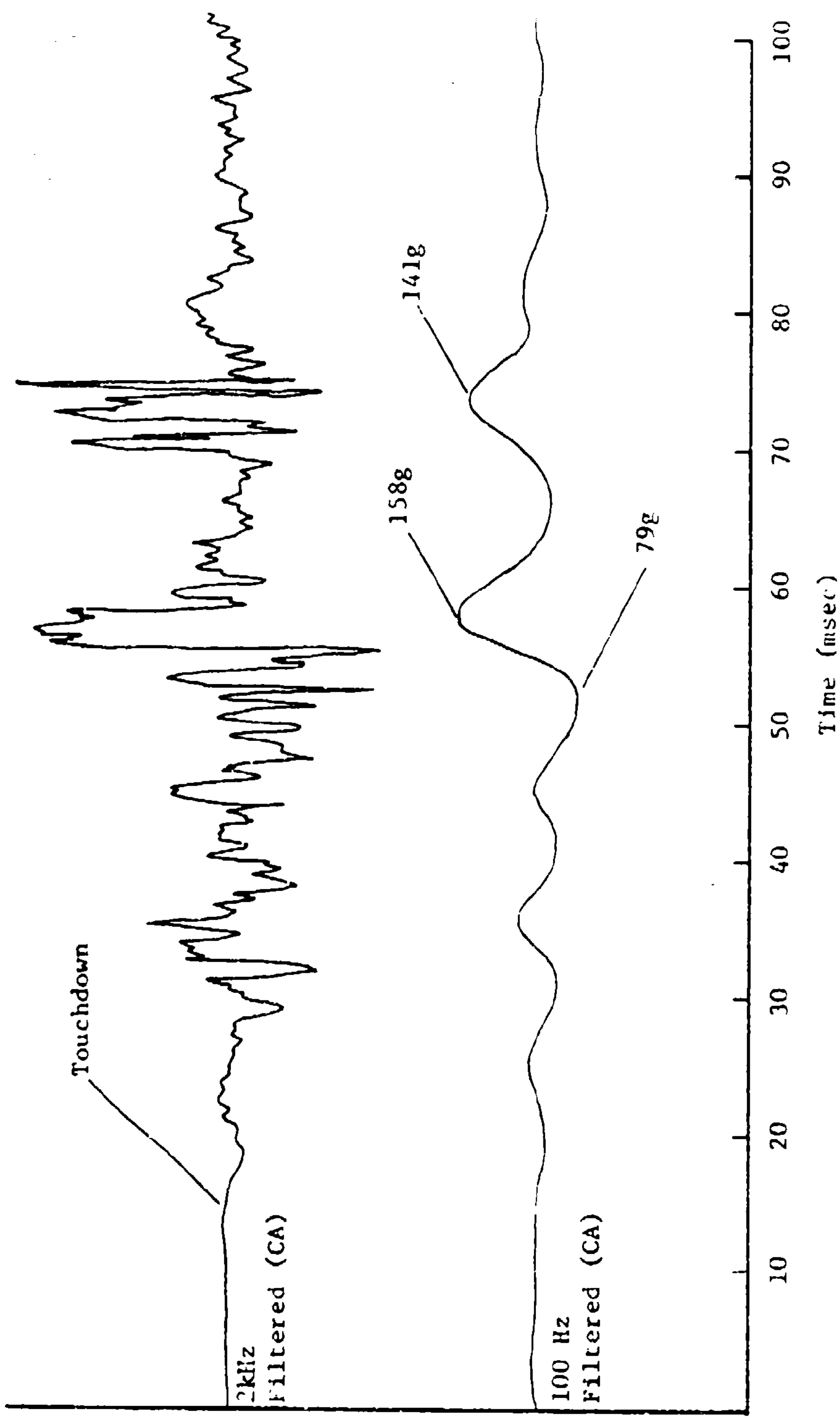


Figure 25 - Aircraft Vertical Acceleration Vs. Time

Pressure developed in the inflatable restraint reached a maximum of 9.6 psi. This is considerably less than was experienced during the horizontal sled tests, but it is to be expected since peak pressure results from the compression of the bladder as the occupant's torso loads the straps. In this situation, the motion is directed predominantly downward into the seat bucket. The severe deformation of the seat absorbs a good deal of energy resulting in reduced strap loads and lower internal pressure. Figure 16 shows not only the failure of the seat pan but also the tearing of the seat back due to the strap loading. Figure 16 also reveals the inflatable restraint in a partially inflated condition which illustrates its semiporous nature. This property will facilitate removal of the restraint by the wearer so that he can exit the wreckage.

ACKNOWLEDGEMENT

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